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FIELD-PLOT COMPARISONS OF DDT AND OTHER
NEW MATERIALS FOR CONTROL OF CATERPILLARS ON CABBAGE

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Several series of studies have been made for the control of caterpillars that commonly attack cabbage and related plants in the South. Arsenical and fluorine compounds, pyrethrum, and rotenone-containing materials have been tested, and the results published (2, 3, 5). One series of studies was begun in the fall of 1932 and continued through the spring of 1937 to test the effectiveness of pyrethrum and rotenone-containing materials and combinations of them when applied at various intervals. Another series of toxicity studies was begun in the fall of 1941 and continued through the spring of 1948 to test materials that might be used to conserve or replace the insecticides then in general use—the arsenicals because of their extreme toxicity and the others because of their scarcity or low toxicity to certain species of insects. Particular attention was given to DDT after its high effectiveness against most of the test insects became apparent in the first trials of this material in the fall of 1943. This publication has to do with the toxicity tests made from 1941 to 1948, inclusive, and with DDT-residue studies made in 1945.

METHODS

A total of 54 field-plot experiments were conducted at the Clemson College Truck Experiment Station, Charleston, S. C., on spring and fall plantings of cabbage grown during 14 crop seasons. Each insecticide was used on 4 to 12 (usually 4 to 6) randomized-block replications of field plots consisting of 1 to 3 rows of plants. Two replications were made of 12- and 15-row plots. The rows usually were 3 feet wide and 50 feet long and bore about 45 plants. An unplanted alley 3 feet wide separated the ends of plots.

One to nine applications (usually 1 to 4) of each material were made in each experiment. Dusts were applied with rotary hand machines, sometimes used in conjunction with a cloth-covered hood and a cloth apron, which reduced insecticide drift between plots as well as gave more uniform

1/ In cooperation with the South Carolina Agricultural Experiment Station.

coverage of the plants. Sprays were applied with a knapsack hand machine that operated at fairly constant pressure. One or two trips per row were made with the duster and one to three trips with the sprayer, depending upon the size of the plants. The quantity of dust applied per acre at any one time ranged from 9 pounds on small plants to 37 pounds on large plants, and the averages for the individual experiments ranged from 20 to 24 pounds. Spray dosages ranged from 57 to 103 gallons and averaged 90.5 gallons per acre-application.

Except for ready-mixed dusts, the dust mixtures were prepared in a 2-quart, electrically operated pebble mill, a 50-pound-capacity sifting and ribbon-type mixing machine, or a 100-pound-capacity mixer of a combination of the ribbon and hammer mill types. Each lot was run about 30 minutes in the pebble mill or about 15 minutes in the larger mixers. Unless otherwise specified, either pyrophyllite or a flaky talc was the diluent of the laboratory-mixed dusts. Talc was used almost exclusively after it was found that pyrophyllite was abrasive to the dust guns.

The impregnated DDT dusts were prepared by dissolving technical DDT (having a setting point of 89° or 90° C.) in a slightly heated, nonvolatile, commercial solvent, consisting of di- and tri-methyl naphthalenes, and spraying the solution into a flaky talc in the mixing chamber of a dust-blending machine in operation.

Results are based on relative numbers of caterpillars, by species, surviving on comparable numbers of plants of each plot, and, in some experiments in which the materials were applied several times, upon the proportions of caterpillar-damaged plants produced. Pupae were included in survival counts that followed two or more insecticide applications. These survival and yield data were obtained from plants within the inner 44 feet of each plot, and on the middle row of 3-row plots. Totals of 40 to 600 plants receiving each insecticide in each experiment were examined, the number usually depending upon the size of the plants and the abundance and distribution of the insects. As a rule, between 10 and 25 plants per plot were examined between the second and fourteenth days after each insecticide application. Grading of plants at harvest followed the classification described by Reid (1). Plants classed as caterpillar damaged were those prevented by caterpillars from producing any head and those whose firm head and four "wrapper" leaves were ineligible to U. S. Grade No. 1 because of excessive caterpillar injury.

RESULTS

The terms "superior" and "inferior" applied to the various materials mean that the differences between surviving caterpillar populations were significant at odds of 19 to 1, or greater. The terms "greatly inferior" and "greatly superior" denote high significance (odds of 99 to 1). In general, caterpillar reductions of 95 percent and above, and not more than 1 or 2 percent of plants damaged by caterpillars, will be regarded as excellent control; reductions of 85 to 94 percent, and not more than

about 5 percent of the plants damaged, as good or satisfactory control; reductions of 50 to 84 percent, and not more than 10 percent of the plants damaged, as fair control; and lower reductions or greater numbers of plants damaged as poor control. In this publication several noctuids comprised largely of four species, namely, the black cutworm (Agrotis ypsilon (Rott.)), the granulate cutworm (Feltia subterranea (F.)), the corn earworm (Heliothis armigera (Hbn.)), and the fall armyworm (Laphygma frugiperda (A. & S.)), will be considered as a group and referred to by their subfamily name, Agrotinae.

Barium Fluosilicate

Barium fluosilicate dusts of approximately 75-percent strength (including a commercial mixture containing 72 percent of barium fluosilicate and 8 percent of cryolite) gave fair control of the cabbage looper and Agrotinae. A 50-percent barium fluosilicate dust gave only fair kill of the cabbage looper, imported cabbageworm, and diamondback moth. As used, barium fluosilicate proved about as effective as cryolite in comparable dosages.

Benzene Hexachloride

Technical benzene hexachloride dusts of 1-, 2-, and 3- percent gamma-isomer content gave good to excellent control of the imported cabbageworm, diamondback moth, and Agrotinae, but only fair to good control of cabbage loopers. Dusts containing 2 and 3 percent of gamma gave high reduction of cross-striped cabbageworms. These three dilutions were about equally effective against the all-species caterpillar infestations, except in one test where a 3-percent gamma dust was superior to a 1-percent dust. A 0.3-percent gamma dust gave 47 to 74 percent kill of the imported cabbageworm, diamondback moth, and looper in two tests. An essentially pure gamma-isomer dust of 1-percent strength proved about as toxic as a technical benzene hexachloride dust of 1-percent gamma content to each of the species present during a spring and a fall test. A technical benzene hexachloride suspension spray tended to be slightly more effective than a dust supplying the same dosage of gamma isomer. A suspension spray containing about 0.03 percent of essentially pure gamma benzene hexachloride proved more effective than a 70-percent cryolite dust against cabbage webworms.

Benzene hexachloride dusts of 1-percent gamma strength gave excellent control (90 percent or higher) of turnip aphids and cabbage aphids on cabbage in 1947 and 1948. Applications of a technical benzene hexachloride dust (2-percent gamma) on the foliage every 7, 10, or 14 days (with totals of 8, 5, and 4 applications, respectively) appreciably reduced the populations of a root aphid, Pemphigus sp., on cabbage during the fall of 1947. During the harvesting period the roots of 71 percent of the untreated plants had light to moderate infestations, and 7 percent of the plants had heavy infestations. From 24 to 30 percent of the treated plants had light to moderate populations of this aphid, and 0 to 1 percent had high ones. Evidently either the insecticide was absorbed by the plant or a sufficient quantity to affect the aphids fell on the soil surface and was mixed into the soil by the cultivation operations.

A technical benzene hexachloride dust (2-percent gamma) applied every 7 and 10 days proved more effective against caterpillars than when applied every 14 days. No difference was shown between the 7- and 10-day intervals.

No appreciable plant injury was noted from several applications on all sizes of cabbage of a technical benzene hexachloride dust (1-percent gamma) and a suspension spray giving comparable dosages of the gamma isomer. Technical benzene hexachloride dusts of 2- and 3-percent gamma content and a suspension spray at dosages comparable to the 2-percent dust caused no apparent injury when used on small cabbage plants. Applications made just before the plants began heading and during the heading period caused slight to severe plant burning, the spray doing most damage. For example, in one test a 2-percent gamma dust caused slight injury to 60 percent of the heading plants; and the spray caused slight injury to 50 percent of these plants, moderate injury to 39 percent, and severe injury to 7 percent. These plants got no earlier applications. In another experiment the first two applications of 2- and 3-percent gamma dusts did no apparent burning, the third dusting (just before heading began) caused slight injury to 25 percent of the plants, and the fourth application slightly injured 33 percent of the plants and moderately injured 8 to 10 percent.

Some plants received eight preheading applications of a technical benzene hexachloride dust of 2-percent gamma strength during the fall of 1947. No objectionable odor or taste was noted by 9 of 10 persons who sampled the raw or the cooked cabbage. One person, who does not like cooked cabbage, stated that the treated sample had a disagreeable odor. There were no other indications during the course of the studies that benzene hexachloride will impart an objectionable flavor or odor to cabbage, even though the material is used after the plants begin heading.

Benzene hexachloride compared favorably with DDT at the same strength of active ingredient against the imported cabbageworm, the diamondback moth, and the Agrotinae when applied every 7 or 10 days, but was less effective than DDT when used every 14 days. Benzene hexachloride was generally less effective than DDT against the cabbage looper.

Chlordane

A 5-percent chlordane dust was fairly toxic to the cabbage looper and Agrotinae, but relatively ineffective against the imported cabbageworm, in two spring tests and one fall test. A 3-percent chlordane dust was not very toxic to either the looper or the imported cabbageworm in two spring experiments. A chlordane suspension spray and an emulsion spray gave good to excellent reductions of the looper and imported cabbageworm and were superior to a 3-percent chlordane dust when applied at comparable dosages of active ingredient. This dust mixture did not have good dusting qualities.

Chlordane dusts usually proved inferior to DDT dusts of comparable strengths. No plant injury was noted from the use of chlordane on cabbage.

2-Chlorofluorene

A spray consisting of 4 pounds of a 20-percent 2-chlorofluorene product to 50 gallons of water gave only slight control of the cabbage looper and no apparent reduction of the imported cabbageworm and diamondback moth in one experiment.

Copper Arsenate

In a 1945 fall experiment, a dust containing 50 percent of basic copper arsenate (with sulfur as the diluent) and a spray containing 10 pounds of basic copper arsenate to 100 gallons of water, plus a commercial spreading and sticking agent, were inferior against the cabbage looper and climbing cutworms to a spray containing 8 ounces of technical DDT to 100 gallons of water.

Cryolite

For comparison, cryolite was considered as the standard insecticide during the early part of the series of tests reported in this paper. The material was the most readily available insecticide for caterpillar control on cabbage and related crops. Previous studies by Reid *et al.* (2) had shown, however, that cryolite was only partially effective against the various species of caterpillars. DDT was regarded as the standard insecticide after its greater effectiveness became apparent.

Cryolite dusts containing 50 or 70 percent of sodium fluoaluminate gave fair to good control of the cabbage looper, the diamondback moth, and the cabbage webworm when used every 7 to 10 days. The 50-percent dilution often did not provide adequate control of the imported cabbageworm and the Agrotinae. This strength did not give adequate control of a heavy infestation of the cabbage webworm during the fall of 1944. Dusts of 70 and 90 percent strengths gave satisfactory control of this infestation. No significant differences were found between cryolite dusts of 70 percent and 90 percent sodium fluoaluminate content.

When used as dusts of 50-percent sodium fluoaluminate strength, a natural cryolite of relatively low sodium fluoaluminate content proved as effective in a 1943 spring-crop experiment against the looper, imported cabbageworm, and diamondback moth as a natural cryolite of the usual initial analysis.

The addition of 1 percent, by weight, of a light grade of mineral oil of the "straw" or "pale" oil type ^{2/} significantly increased the

^{2/} The oil was of paraffinic base and had a viscosity (Saybolt at 100° F.) of approximately 75 seconds and an unsulfonated residue of approximately 90 percent.

effectiveness against the imported cabbageworm of a cryolite dust containing 50 percent of sodium fluoaluminate. The oil also tended to increase the control of the cabbage looper and diamondback moth afforded by cryolite in this experiment. The oil decreased the dusting quality of the cryolite mixture, which was none too good without oil. Similar use of this oil in a cryolite dust in a later experiment was of no apparent value.

Cryolite proved inferior to DDT in all comparisons for all-species caterpillar control. A cryolite dust of 70-percent sodium fluoaluminate content was inferior to a 3-percent DDT dust against the all-species caterpillar population in one experiment, and one of 50-percent sodium fluoaluminate content was inferior to 10-, 3-, and 1-percent DDT dusts in others. Cryolite was inferior to DDT in immediate effect upon the caterpillars, and also in lasting protection.

DDT

DDT gave good to excellent caterpillar kill, and its effect was more lasting than that of any other material. Against mixed populations of the more important species of caterpillars DDT proved more effective than any material tested prior to 1943. Several insecticides tested later proved as effective as DDT against one or more species of caterpillars. None, however, were superior to comparable dosages of DDT. DDT was found to be ineffective against aphids. Several other new insecticides, notably benzene hexachloride and parathion, proved highly toxic to the turnip aphid and the cabbage aphid, as well as to the caterpillars. They will be discussed under their respective headings.

In the small-plot field experiments no significant differences in the control of the all-species caterpillar populations were found between DDT dusts of 2-, 3-, 5-, and 10-percent strengths. These mixtures usually reduced the infestations of each species by approximately 90 percent or more. Dusts of 3- and 5-percent strengths proved superior to a 1-percent dust in half the comparisons. A 10-percent dust was superior to a 1-percent dust, and a 2-percent dust was superior to a 0.5-percent one, in the only comparisons made of these dilutions. A 1-percent dust provided adequate control of the cabbage looper, imported cabbageworm, and diamondback moth in one spring experiment, and a 3-percent dust always gave adequate control of these species when applied periodically and carefully during the small-plot tests. When a 1-percent DDT dust was applied with a hand duster every 14 days, 8.3 percent of the plants were destroyed by the cabbage webworm. Similar use of a 2.5-percent dust gave adequate webworm control. Observations in commercial plantings, in which large dusting machines that did not concentrate the insecticide on the plants were used, indicated that 3-percent dusts applied at the usual rates of 15 to 25 pounds per acre did not always give adequate control of the cabbage webworm and Agrotinae on fall cabbage. This was especially true when the plants were small and during rainy periods. Dusts of 5-percent strength used at ordinary rates and 3-percent dusts used at 30 to 40 pounds per acre gave satisfactory control of these more resistant species of caterpillars when properly applied. Suspension sprays proved at least

as effective as dusts when applied at comparable dosages. An emulsion spray apparently gave nearly perfect control in the one spring experiment in which it was used.

When applied every 10 to 14 days, DDT dusts of 3-percent and higher strengths usually provided adequate caterpillar control. Use of these materials every 21 days was not always adequate; damage sometimes occurred on the untreated new growth regardless of the strength of dust applied, particularly when the imported cabbageworm was abundant. Most of the eggs of this species are laid on the new growth near the center of the plant.

Impregnated DDT dusts of 0.5- and 1-percent strengths proved superior to ordinary dusts of the same DDT content. Simply adding the same proportion (2 percent) of this solvent to ordinary 0.5- and 1-percent DDT dusts during the mixing process gave dusts that were as effective as the impregnated ones. An impregnated 1-percent dust and a 1-percent dust to which this solvent was added were superior to an ordinary 3-percent dust in one experiment and were not inferior to ordinary 3-, 5-, and 10-percent DDT dusts in other experiments. The addition of 2 percent of a light mineral oil ²/ significantly increased the effectiveness of 0.5- and 1-percent DDT dusts in two of four experiments. This oil evidently was not quite so beneficial as the solvent. The dusts containing this solvent or the oil did not have such good dusting qualities as ordinary mixtures. A more absorptive diluent might have been of benefit.

Dust mixtures containing 2 percent of DDT and either 2 percent of nicotine (either sulfate or "free" form) or 0.75 percent of rotenone proved effective against light to moderate infestations of caterpillars and turnip aphids on cabbage. Storage of these dusts for 6 months did not affect the toxicity of the DDT-rotenone mixture but tended to decrease that of the DDT-nicotine mixture.

DDT usually was not applied during the heading period of cabbage growth, and in most of the experiments only a few applications, sometimes only one, were made. In order that adequate caterpillar populations for the insecticide comparisons would be assured, plantings for the spring crop often were made later than in commercial practice. Nevertheless only 1.5, 2.4, 4.9, and 9 percent of the plants getting 10-, 5-, 2.5- or 3-, and 1-percent DDT dusts, respectively, were ineligible to U. S. Grade No. 1 because of caterpillar damage. Usually not more than 1 or 2 percent of the plants were damaged in plots or fields where adequate control was attempted.

No plant injury from the use of DDT was observed on cabbage, collards, and broccoli at various stages of growth. As many as seven applications of a 10-percent DDT dust at an average rate of 16 pounds per acre were made on cabbage during a spring season, and as many as four applications at an average of 20 pounds per acre during a fall season. Four applications

of a 5-percent DDT dust at an average rate of 37.5 pounds per acre also were made on cabbage during a fall season. The broccoli and collards received three applications of a 5-percent dust at an average dosage of about 13 pounds per acre. These dustings were made with hand machines that concentrated the insecticide on the plants.

Preventive use of DDT.--Throughout the series of small-plot experiments and in observations of commercial plantings the use of DDT during the preheading stage of cabbage growth appreciably reduced, and sometimes eliminated, the need for caterpillar control thereafter. Results were particularly good when a heavy application was made just before the plants began heading. Effects of the DDT upon the caterpillar population often were apparent for 3 weeks to a month. Fall plantings usually needed no further control measures. A preventive application of DDT dusts of 2- to 5-percent strengths made on spring plantings shortly before heading began was found to be well worth while, even though the caterpillar population was not sufficiently high to require control measures when the dusting was done. For example, the following observations were made in three commercial cabbage plantings in the spring of 1946: Not more than 1 percent of plants getting one preheading application of a 2- or 2.5-percent DDT dust, at a rate of 20 to 35 pounds per acre, were "damaged" (made ineligible to U. S. Grade No. 1) by caterpillars during the heading and harvesting period. No other insecticide was used. Untreated portions of these three fields had 4, 6, and 24 percent of caterpillar-damaged plants.

Diluents of DDT dusts.--Tests were made in both spring and fall to compare a kaolin clay, a flaky talc, pyrophyllite, and sulfur, as diluents for DDT dusts. A dust containing 10 percent of DDT in pyrophyllite was further diluted with these materials to give finished dusts containing 1 percent of DDT. No significant differences were found among the dusts containing kaolin clay, flaky talc, or pyrophyllite. However in the spring but not in the fall experiment the kaolin dust proved superior to the sulfur dust. The dusts used in the fall experiment were remaining portions of those tested in the spring.

DDT-residue studies.--The quantities of insecticidal residue that might be present on cabbage at harvest after the use of DDT at various times during plant growth were studied during the spring and fall of 1945. Chemical analyses were made by the Division of Insecticide Investigations.

The usually marketed portion (firm head and four loose or partly loose "wrapper" leaves) of spring plants given one application of a 2.5-percent DDT dust just before heading began (about 4 weeks before harvest) showed only 0.02 part per million of DDT when harvested. Plants given this preheading dusting and another about midway of the heading period bore 0.8 p.p.m. of DDT. Plants that received only the heading application showed 0.7 p.p.m. Rainfall was 1.72 inches between the two applications and 0.48 inch between the last dusting and harvest. Residues

found during the fall experiments were somewhat higher. Fall cabbage given seven applications of a 2-percent DDT dust between the appearance of the first true (crinkly) leaves and the beginning of heading (about 35 days before harvest) showed no DDT residue. Cabbages dusted until 21 days before harvest bore 6.6 p.p.m. of DDT, and those dusted until 7 days before harvest bore 9 p.p.m. These applications were made with a hand-operated duster at intervals of approximately 10 days. As has been true in earlier residue studies, the greater portion of the insecticide deposit was found on the "wrapper" leaves. On the plants dusted until a week before harvest, the two outer wrapper leaves showed 59.9 p.p.m. of DDT, the two inner wrapper leaves 54.5 p.p.m., and the firm head 0.6 p.p.m. Rainfall between the first dusting (August 23) and the beginning of heading (about November 26) was 19.34 inches, that during the last 35 days before harvest was 1.84 inches, that during the last 21 days was 0.29 inch, and that during the last 7 days was only 0.05 inch.

The fall cabbage that received applications of DDT by hand dusters apparently bore considerably larger quantities of DDT residues at harvest time than did those given comparable applications by a power duster having six nozzles. A DDT residue of 0.11 p.p.m. was found at harvest on the usually marketed portion of cabbage receiving six or seven power applications of a 2-percent dust, the last being made about 21 days before harvest.

The DDT residues found in these studies were considerably lower than those that followed similar use of arsenical insecticides in 1943, and in earlier tests by the authors reported by White (5) and by Smith et al. (4). There was sufficient DDT on the plants, however, to indicate that it would be unsafe for DDT insecticides to be applied to any portion of the plant to be marketed or used as food. In the 1943 experiment, the firm head and four wrapper leaves of cabbage that got one application of a 50-percent lead arsenate dust just before heading began and another midway of the heading period showed 0.0283 grain of arsenic trioxide per pound (approximately 4 p.p.m.) at harvest, and those given similar applications of undiluted calcium arsenate bore 0.0398 grain of arsenic trioxide per pound (approximately 5.7 p.p.m.). The usually marketed portion of cabbage given similar applications of a cryolite dust of 50-percent sodium fluoaluminate content showed only 0.0087 grain of fluorine per pound (approximately 1.2 p.p.m.).

Derris malaccensis

A Derris malaccensis dust stated to contain 1.13 percent of total ether extractives, with only a trace of rotenone, was about as effective in one test against the imported cabbageworm, and only slightly less effective against the looper, as a Derris elliptica dust containing the same percentage of total extractives, which included 0.5 percent of rotenone.

Hellebore

Four heading applications of a dust containing 50 percent of powdered domestic hellebore during the fall of 1941 did not give adequate control of the cabbage looper.

Methoxychlor

Dusts containing 1 or 2 percent of methoxychlor gave fair to good reductions of the imported cabbageworm and diamondback moth in one test of each dilution. A 3-percent dust reduced an imported cabbageworm population by 87 percent. Dusts of 1-, 2-, 3-, and 5-percent methoxychlor gave only poor to fair control of the cabbage looper, and the 5-percent dust gave only fair control of the Agrotinae. The all-species caterpillar control afforded by the 5-percent methoxychlor dust was only fair. This dilution proved greatly inferior to a 5-percent DDT dust, and the 3-percent methoxychlor dust was inferior to a 3-percent DDT dust. The methoxychlor dusts caused no apparent plant injury.

Nicotine

A commercial dust of 4.7-percent fixed-nicotine content, applied four times at 8- to 14-day intervals on heading cabbage at rates of 18 to 26 pounds per acre-application, gave poor control of the cabbage looper in a 1941 fall experiment. This dust was greatly inferior to a 0.3-percent pyrethrins dust against the looper, but was as effective against the few small to medium-sized Agrotinae present.

The addition of 2 percent of free nicotine to a 0.15-percent pyrethrins dust significantly increased the kill of diamondback moth larvae, but not that of the cabbage looper and the imported cabbageworm in a single-application test made in the spring of 1942. A spray consisting of one part of nicotine sulfate to 600 parts of water plus 0.5 percent of white laundry soap, applied weekly (4 times at about 100 gallons per acre-application), reduced the proportion of plants damaged by the diamondback moth to 7 percent, as compared to 32 percent in the untreated plots. This spray was of no apparent value against the cabbage looper and imported cabbageworm.

Weekly use of a 3-percent fixed nicotine dust (6 applications at an average dosage of 34 pounds per acre between thinning and harvest of the plants) gave an average of 78 percent control of the diamondback moth, which was adequate for that species. This dust gave an average of 61 percent control of the imported cabbageworm, which was not quite adequate, and gave no appreciable protection against the cabbage looper. The diamondback moth larvae and the loopers each averaged between 5 and 6 per plant, and the imported cabbageworms between 3 and 4 per plant.

Parathion

A 1-percent parathion dust gave excellent control of cabbage loopers and a 0.5-percent dust gave good control of that species and of Agrotinae in a fall experiment. Differences between these dusts and a 5-percent DDT dust were not significant. The parathion dusts also proved quite effective against turnip aphids, green peach aphids, and vegetable weevil larvae on cabbage. The parathion dusts caused no apparent plant injury.

Phenothiazine

A 20-percent phenothiazine dust and a spray containing $1\frac{1}{2}$ pounds of phenothiazine to 50 gallons of water, plus a commercial wetting and sticking agent, gave only fair control of Agrotinae, the cabbage webworm, and the diamondback moth and poor control of the cabbage looper and the imported cabbageworm in two experiments. Phenothiazine, especially in sprays, caused slight injury to stain on cabbage foliage.

Phenoxathiin

A 20-percent phenoxathiin dust and a spray containing 2 pounds of a 50-percent phenoxathiin concentrate to 50 gallons of water, plus a commercial spreading and sticking agent, gave fair control of the diamondback moth, poor control of the cabbage looper, and no apparent reduction of the imported cabbageworm in one test. These materials caused slight to severe injury to the leaf margins and to the margins of holes caused by caterpillar feeding.

Potassium Fluosilicate

Two applications of a 50-percent potassium fluosilicate dust, which had poor dusting qualities, followed by one of a 33-percent dust (used at higher dosage to offset the lower strength) gave fair control of the imported cabbageworm and poor control of the cabbage looper and the diamondback moth. This material was superior to a 50-percent cryolite dust against the all-species infestation, but tended to be inferior to a 50-percent sodium fluosilicate dust. The potassium fluosilicate dusts caused slight to moderate injury to about 9 percent of the plants.

Ryania

One application of a dust containing 50 percent of the ground stems of Ryania speciosa gave fair to good control of the diamondback moth but only poor to fair control of the cabbage looper and the imported cabbageworm. This dust was greatly superior to a 1-percent rotenone dust against the cabbage looper and diamondback moth, but greatly inferior against the imported cabbageworm. A 25-percent ryania dust, which had better dusting qualities than the 50-percent dust, was greatly superior to a 1-percent rotenone dust against the diamondback moth, as effective against the looper, but greatly inferior against the imported cabbageworm. In another test, one application of a 50-percent ryania dust was as effective as a 0.9-percent rotenone dust against the looper (neither gave adequate control), but again greatly inferior against the imported cabbageworm.

Action of the ryania dusts was slightly slower but more lasting than that of the rotenone dust. Caterpillar mortality from ryania dusts was highest between the seventh and tenth days after the dusting. Caterpillar control given by the rotenone dusts was highest on the seventh day, but dropped rapidly by the tenth. No ill effects upon persons handling the ryania dusts or from use of the material on cabbage were noted.

Cabbage plants that received one application of a 50-percent ryania dust on May 14, 1945, had a noticeably lower infestation of onion thrips on May 29 than plants given 0.9-percent rotenone or 1-percent DDT dusts.

Sabadilla

One application of a 20-percent sabadilla-seed dust gave only fair (74 percent) control of the all-species caterpillar population, but was about as effective as a 0.75-percent rotenone dust in an early-season experiment in 1945. A 10-percent sabadilla dust was inferior to the 0.75-percent rotenone one. In a later experiment in the spring of that year, three applications of a 20-percent sabadilla dust gave fairly good control of the imported cabbageworm, but poor control of the looper and the diamondback moth. The 20-percent sabadilla dust was inferior against the all-species caterpillar population to a 1-percent rotenone dust (neither gave adequate control), and both were inferior to a 1-percent DDT dust. A 10-percent sabadilla dust proved relatively ineffective against the caterpillars and was eliminated after the second dusting.

The sabadilla dusts caused no apparent plant injury, but did cause considerable sneezing by persons making the applications.

Soap

Four weekly applications of 1 pound of hard, soda fish-oil soap in 5 gallons of water, followed by similar applications of a spray containing 1 pound of this soap to 8 gallons of water, gave an average reduction of 62 percent of all caterpillars present on cabbage throughout the fall of 1942. These sprays gave best control of the imported cabbageworm and cabbage looper (88 and 85 percent, respectively) and only 20 percent reduction of the cabbage webworm when the infestation was at its peak. Excellent aphid control was provided. These soap sprays, especially the more concentrated one, caused moderate to severe injury to the cabbage. This injury showed up as a stunting of plant growth and a distorting of the leaves. The sprayed plants also were more seriously damaged by winter temperatures, probably because the soap removed much of the waxy bloom from the leaves.

Soap sprays were used in two experiments during the spring of 1943. In the first of these, which involved only one application, a 2-percent solution of a common white cake laundry soap (1 pound to 6 gallons of water) and a similar solution of mild flake soap were tooropy to form a spray in water at 50° F. Sprays at water temperatures of 60° to 70° caused moderate to severe injury to 48 to 85 percent of the plants and killed 50 to 100 percent of the caterpillars. The 2-percent solution of the cake soap caused slight to moderate injury to about half the plants and killed about 35 percent of the caterpillars when applied at 85° to 90° F. A 1-percent solution of the cake soap used at about 80° caused only slight injury to 2.5 percent of the plants and killed only about 25 percent of the caterpillars.

In the other 1943 spring test, four weekly applications of a 1-percent solution of white cake laundry soap caused only slight plant injury, but

was of no appreciable value in the control of caterpillars. Similar use of a spray containing 0.5 percent (1 pound to 24 gallons of water) of this soap and 1 part of nicotine sulfate to 600 parts of water reduced the proportion of plants damaged by the diamondback moth to 7 percent, compared with 32 percent in the untreated plots. But this nicotine-soap spray was of no apparent value against the cabbage looper and imported cabbageworm.

In general, it seems apparent that soap sprays strong enough to give worth-while caterpillar kill will injure cabbage plants enough to offset much, if not all, of their value. Soap sprays of 1- to 2-percent strength may be used by home gardeners at spray temperatures of 80° to 90° F. when caterpillars are abundant and better materials are not available.

Scorodite

One application during November 1943 of a micronized "run of the mine" undiluted scorodite (hydrous ferric arsenate) dust gave fair (a maximum of 63 to 65 percent) reduction of the imported cabbageworm and cabbage looper. This material was supplied by the Division of Insecticide Investigations and contained 27 percent of arsenic, calculated as As_2O_5 , and 32.9 percent of iron, calculated as Fe_2O_3 . It apparently was ground too finely to have good dusting qualities when not diluted. A 50-percent scorodite dust was slightly less effective. No significant differences were shown between the effectiveness of these two scorodite dusts and a 50-percent calcium arsenate dust. The undiluted scorodite was inferior to a 50-percent lead arsenate dust and to a 20-percent paris green dust against the cabbage looper, but as effective as undiluted calcium arsenate dust and a 10-percent paris green dust. The undiluted scorodite was inferior to all these arsenical dusts except the 50-percent calcium arsenate one in the control of the imported cabbageworm.

Scorodite should be of some value against the cabbage looper and imported cabbageworm when used in a control program.

Sodium Fluosilicate

Undiluted and 75-percent sodium fluosilicate dusts gave good to excellent control of the cabbage looper and Agrotinae, but only poor to fair reduction of cabbage webworms. A 50-percent dust gave fair to good control of all the caterpillars. A 50-percent micronized sodium fluosilicate dust, applied seven times at 10-day intervals, gave an average of 92 percent control of the cabbage looper, cabbage webworm, imported cabbageworm, and Agrotinae on a 1943 fall planting. The undiluted dust and the 75 percent dusts that contained no conditioning agent had only fair dusting qualities, which evidently was the chief reason for their poor control of the cabbage webworm. Dusts of 50 percent strength had fair to good dusting qualities, depending upon the diluents. The addition of 12 percent of barium carbonate and 0.6 percent of tricalcium phosphate improved the dustability of 50- and 75-percent sodium fluosilicate dusts

supplied by a commercial agency. Varying proportions of soybean flour, wheat flour, and wheat bran also seemed to make these mixtures more dustable. A dust containing 50 percent of sodium fluosilicate, 49 percent of sulfur, and 1 percent of tricalcium phosphate had good dusting qualities.

Sodium fluosilicate dusts of 50- and 75-percent strengths usually were superior to similar dilutions of cryolite against the all-species caterpillar populations. A 50-percent sodium fluosilicate dust was as effective in one test as a 1-percent DDT dust, but inferior to a 2.5-percent DDT dust. Sodium fluosilicate dusts of 75-percent strength usually were only slightly more effective than those of 50-percent strength.

Sodium fluosilicate dusts caused varying degrees of plant injury, most heading plants being affected. Because it is poisonous to man the material should not be applied on heading cabbage. In general, undiluted sodium fluosilicate caused excessive plant injury, and dusts of 50- and 75-percent dilutions caused slight to moderate burning. The injury done by the 50-percent dusts was usually not of a permanent nature and did not affect the size and appearance of the plants at harvest. Barium carbonate and tricalcium phosphate seemed to reduce the amount of plant injury caused by sodium fluosilicate, as well as to improve its dusting qualities.

TDE

Dusts containing 3 and 5 percent of dichlorodiphenyldichloroethane, which is chemically related to DDT and commonly known as TDE or DDD, were as effective as similar dilutions of DDT in one test against the cabbage looper, the imported cabbageworm, and the Agrotinae. A 5-percent TDE dust gave excellent control of the cabbage looper and the Agrotinae in a 1947 fall experiment, and a 3-percent TDE dust gave fair to good control of the cabbage looper and excellent control of the imported cabbageworm in a 1947 spring experiment.

TOXAPHENE

A 5-percent toxaphene dust gave good control of cabbage loopers, imported cabbageworms, and Agrotinae during one spring and one fall season. A suspension spray providing a comparable dosage of active ingredient gave excellent reduction of these species. In the one experiment in which they were compared, a 5-percent toxaphene dust was superior to a 3-percent one against the imported cabbageworm at the time of the first of two insect counts and tended to be superior against the cabbage looper at the third and most important count. Toxaphene dusts at 3- and 5-percent strengths showed considerable toxicity to the cabbage aphid (62 to 95 percent reduction) and some toxicity to the green peach aphid (54 to 58 percent reduction) in limited tests, but were slower acting than nicotine or benzene hexachloride.

Toxaphene dusts of 3- and 5-percent strengths were, in general, about as effective as similar strengths of DDT. There were indications that toxaphene might be slightly more toxic than DDT to the fall armyworm and certain climbing cutworms and less toxic than DDT to the imported cabbageworm. In a fall experiment at the time of thinning, there were significantly fewer caterpillar-damaged plants on plots receiving a 5-percent toxaphene dust than on those given a 5-percent DDT dust. This difference was not so apparent during later observations. A 3-percent toxaphene dust was inferior to a 3-percent DDT dust against the imported cabbageworm throughout a spring experiment at which time this species was abundant.

Xanthone

A commercial dust containing 25 percent of xanthone gave only poor to fair control of the cabbage looper, the diamondback moth, and the Agrotinae in the one test in which it was used. This dust showed no toxicity to the imported cabbageworm.

SUMMARY

Field-plot tests were made of various materials that might conserve or replace arsenical, fluorine, rotenone, and pyrethrum insecticides in the control of caterpillars on cabbage and related crops. The studies were conducted at Charleston, S. C., during the 14 crop seasons from the fall of 1941 through the spring of 1948. Twenty-three materials were applied with hand-operated dusters or sprayers at 20 to 25 pounds of dust per acre-application and 90 gallons of spray.

Most of the materials differed in toxicity to the various species of caterpillars commonly attacking cabbage in the South--the cabbage looper (Trichoplusia ni (Hbn.)), the imported cabbageworm (Pieris rapae (L.)), the diamondback moth (Plutella maculipennis (Curt.)), the cabbage webworm (Hellula undalis (F.)), and several species of the subfamily Agrotinae, chiefly the corn earworm, the fall armyworm, and climbing cutworms.

DDT was the most effective against mixed infestations of caterpillars of all the materials extensively tested. DDT suspension and emulsion sprays were as effective as, and sometimes superior to, dusts applied at the same dosage. In ordinary dusts prepared from ground DDT, 3 percent of DDT was usually sufficient when applied every 10 to 14 days, but 5 percent was sometimes required in fall plantings to control the cabbage webworm and Agrotinae. One-percent DDT dusts, however, when prepared from a DDT solution or from ground DDT plus 2 percent of a mixture of di- and tri-methyl naphthalenes were as effective as ordinary 3-percent dusts. DDT was used on cabbage, collards, and broccoli at various stages of growth without plant injury. The use of DDT during the preheading stage of cabbage growth greatly reduced and sometimes eliminated the need for caterpillar-control measures thereafter. A preventive application just before the plants began heading was found to be well worth

while in combating light, but increasing, infestations. In order to avoid DDT residues on the usually marketed portion (firm head and 4 wrapper leaves) of cabbage, it was necessary to discontinue DDT applications when the heads began to form.

Technical benzene hexachloride was approximately as toxic as DDT, in equal dosages of active ingredient, to each of the more important caterpillars except the cabbage looper, but its effect was not so lasting. Dusts containing 1 percent of gamma isomer were quite effective against the cabbage aphid and the turnip aphid and did not cause plant injury. Those of 2- and 3-percent strengths apparently did not injure small plants, but burned heading cabbage.

In a limited number of tests 3- and 5-percent toxaphene dusts and 3- and 5-percent TDE dusts were approximately as effective as similar DDT dusts, except that toxaphene did not appear to be quite as toxic as DDT to the imported cabbageworm. A 1-percent parathion dust compared favorably with 3- and 5-percent DDT dusts against the caterpillars and was quite effective against the cabbage and turnip aphids. As used, chlordane, methoxychlor, cryolite, sodium fluosilicate, and basic copper arsenate proved generally inferior to DDT.

Materials that proved fairly toxic to one or more species of caterpillars, but did not usually provide satisfactory control of prevailing mixed infestations, were fixed nicotine, sabadilla-seed powder, ground stems of Ryania speciosa, and a relatively strong soap-nicotine spray. Sodium fluosilicate dusts of 50- to 75-percent strength showed considerable toxicity to the caterpillars, but did not have good dusting qualities and sometimes caused moderate to severe plant injury. Scorodite, undiluted and as a 50-percent dust, was about as toxic as a 50-percent calcium arsenate dust against the imported cabbageworm, but inferior to this material and to 20-percent lead arsenate and paris green dusts against the cabbage looper.

A domestic hellebore dust, a 2-chlorofluorene spray, a phenothiazine dust and spray, a potassium fluosilicate dust, a phenoxathiin dust and spray, and a xanthone dust were relatively ineffective.

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